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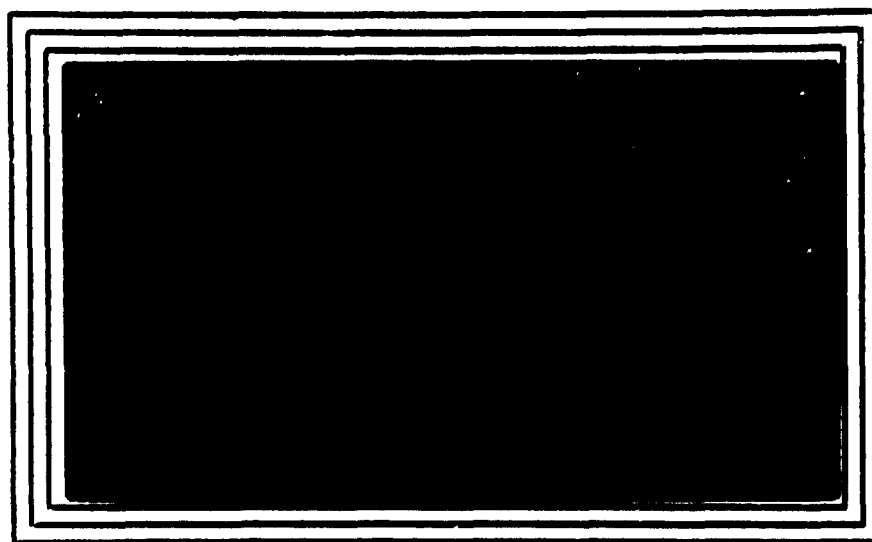
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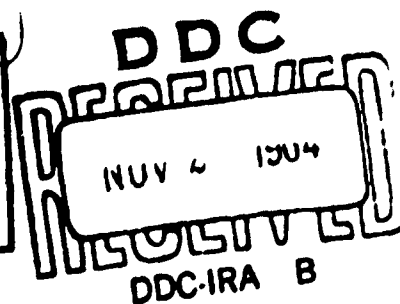
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**RESEARCH AND DEVELOPMENT DEPARTMENT**

**U. S. NAVAL AMMUNITION DEPOT - CRANE, INDIANA**



RDTR No. 45  
25 September 1964

RELATIONSHIPS OBSERVED  
IN COLORED FLAMES

U. S. NAVAL AMMUNITION DEPOT  
Crane, Indiana

RDTR No. 45  
25 September 1964

RELATIONSHIPS OBSERVED  
IN COLORED FLAMES

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SIGNED

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ABSTRACT

Excitation purity of a sodium-yellow flame was observed to be a decreasing function of the magnesium content in the flare. The chromaticity coordinates representing a wide variety of sodium-yellow, barium-green and strontium-red flares when plotted on a chromaticity diagram appear to take the form of straight lines which converge toward a common point. Several theories are proposed to explain the observations, the convergence point and the intercept point of the convergence line with the chromaticity diagram perimeter.

# RELATIONSHIPS OBSERVED IN COLORED FLAMES

## 1. PURPOSE

The purpose of this paper is to report and discuss observations made during a flare improvement program.

## 2. BACKGROUND

Pyrotechnic compositions formulated to produce yellow colored flames were being studied in an effort to test some of the color production theories advanced earlier by Douda<sup>1</sup>. During the program it was observed that some of the test results were related to one another in a unique manner. These are the observations that will be presented.

## 3. EXPERIMENTAL

Test specimens were prepared with formulae as shown in Table I. The color data recorded for the eight batches are shown in Table II.

Table I. FORMULATIONS (Percent by Weight)

| Ingredients              | 1  | 2  | 3  | Batch |    | 6  | 7  | 8  |
|--------------------------|----|----|----|-------|----|----|----|----|
|                          |    |    |    | 4     | 5  |    |    |    |
| Magnesium -----          | 20 | 40 | 20 | 30    | 25 | 25 | 22 | 20 |
| Sodium Nitrate -----     | 55 | 55 | 50 | 65    | 60 | 70 | 63 | 50 |
| Sodium Oxalate -----     | 20 | -- | 20 | --    | 10 | -- | 10 | 20 |
| Potassium Nitrate -----  | -- | -- | 5  | --    | -- | -- | -- | -- |
| Potassium Perchlorate -- | -- | -- | -- | --    | -- | -- | -- | 5  |
| Binder Solution -----    | 5  | 5  | 5  | 5     | 5  | 5  | 5  | 5  |

Table II. COLOR DATA (Arithmetic Mean)

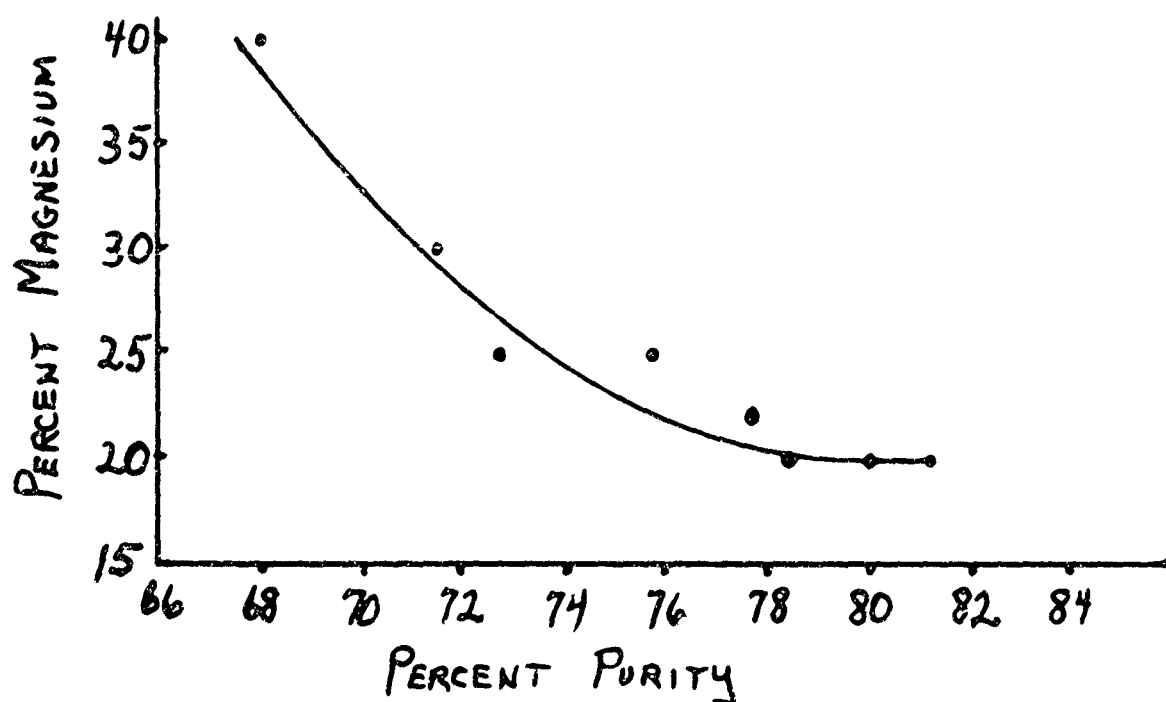
| Attribute                | 1   | 2   | 3   | Batch |     | 6   | 7   | 8   |
|--------------------------|-----|-----|-----|-------|-----|-----|-----|-----|
|                          |     |     |     | 4     | 5   |     |     |     |
| Dominant Wavelength(mu)- | 590 | 588 | 591 | 587   | 587 | 587 | 590 | 591 |
| Purity (%) -----         | 81  | 68  | 80  | 71    | 76  | 73  | 78  | 78  |

#### 4. OBSERVATIONS

##### a. Magnesium Content vs. Excitation Purity

A relationship was observed between percent excitation purity and percent magnesium in the formula as shown graphically in Figure 1.

Figure 1



The trend of decreasing purity with increasing magnesium content suggests the formation of an emitter which is a compound of magnesium, such as magnesium oxide. This suggestion is made because of the apparent dependence of the purity upon the quantity of magnesium in the formula. On the other hand, the relationship between magnesium content and excitation purity may be the result of changes in flame temperature. As the magnesium content increases, the flame temperature may be increasing thereby causing a



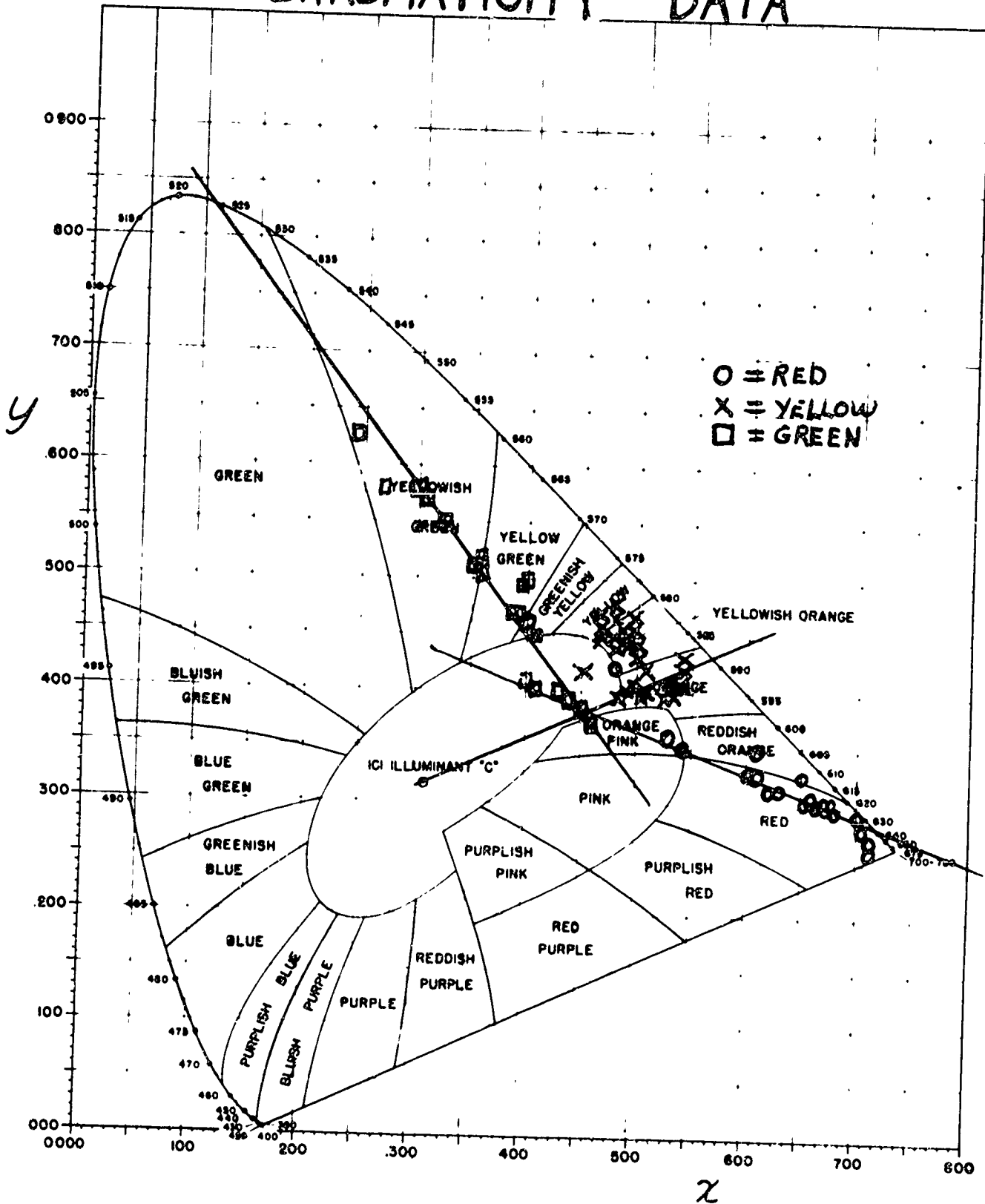
proportionally greater emission increase in the blue region than at other wavelengths. As described by Barrow and Caldin<sup>2</sup>, the increase in blue emission will cause a large reduction in excitation purity. In addition, during a study of green flames, Douda<sup>3</sup> observed that blue energy and BaO emission combine to cause purity reduction as an increasing function of temperature. As a result of these observations, it can be theorized that the relationship between purity and magnesium content is most likely the combination of a temperature effect and emission from a magnesium compound such as the oxide or halide.

b. Color Convergence and Wavelength

(1) As a result of the observed relationship discussed in the preceding paragraph, it was decided to determine if a similar correlation is evident for flares of other colors. In order to study the phenomenon from a different aspect, chromaticity data for green, yellow and red flares were taken randomly from the files and plotted on a chromaticity diagram. In the selection of these data, no regard was made to the flare formula or to the percent of magnesium. From Figure 2, the chromaticity diagram shown on the next page, it is apparent that the points representing each of the three colors of flares converge toward a central location ( $x = .455$ ;  $y = .380$ ). The only ingredient that these flares have in common is the magnesium fuel. That being the case, it is hypothesized that the point of convergence represents some form of magnesium emission.

Figure 2

## CHROMATICITY DATA



As evidenced by the discussion concerning magnesium content and excitation purity, it is difficult to separate the temperature effect from the composite. Although the point of convergence appears to be solely dependent upon emission from a magnesium compound, the potential influence of the temperature of the flame upon the emitting species must not be disregarded.

(2) Hardy<sup>4</sup> describes the rules of color additive mixtures which state that all mixtures of two colors on the chromaticity diagram fall on the line drawn between those two colors. Johnson<sup>5</sup> suggests that by the application of these rules, the dominant wavelengths of non-halogenated colored flames can be adjusted. As illustrated in Figure 2, the results are dispersed along the line between the point of convergence of the three lines and the intercept with the perimeter of the chromaticity diagram. Thus, the observed behavior appears to respond in accordance with the rules of color additive mixtures using (a) the convergence point as a composite representation of magnesium compound emitter and temperature effect and (b) the intercept with the diagram perimeter as a representation of the dominant color emitter. For example, the yellow convergence line intercepts near 590 mμ which is the strongest emission line of atomic sodium. Therefore, it is proposed that all formulations of sodium and magnesium compounds will produce colors which fall between the convergence point and the perimeter intercept near 590 mμ.

(3) The information in Figure 2 for green flames is based

upon barium formulations and for red flames upon strontium. In a manner analogous to sodium, the barium-green flame colors are dispersed about the convergence line which intercepts at 524 mμ. Strong BaCl emissions have been reported at 524 mμ and for BaOH at 527mμ. In like manner, the strontium red flame colors show an intercept at about 640 mμ. Strong SrCl and SrOH emissions occur in this region. These observations tend to confirm the theory that (a) atomic sodium is the dominant emitter in yellow sodium flames, (b) BaCl and BaOH dominate in green barium flames, (c) SrCl and SrOH dominate in red strontium flames and that (d) colored flames based upon these metals will exhibit colors defined by the convergence line between the convergence point and the diagram perimeter intercept.

(4) The points on the chromaticity diagram which are grouped in the area of  $x = .480$  and  $y = .460$  were disregarded for purposes of locating the yellow line which converges with the green and red lines. Those readings were recorded about seven years ago from formulae substantially the same as the formulae represented by the points grouped about the yellow convergence line. Thus there was doubt concerning their validity. Because of this, samples with the same formulae were prepared to determine their chromatic values using the latest available techniques and equipment. Test of these new samples shows that the color falls on the yellow convergence line near  $x = .520$  and  $y = .406$ . Thus the shift of the group of points around  $x = .480$  and  $y = .460$  away from the yellow

convergence line is attributed to instrumentation error.

## 5. SUMMARY

During the program, two relationships were observed. They are (a) that as the magnesium content in a sodium based flare increases, the excitation purity decreases and (b) that the chromaticity coordinates which represent a wide variety of sodium-yellow, barium-green and strontium-red flares when plotted on a chromaticity diagram appear to take the form of straight lines which converge toward a common point. The magnesium vs. purity relationship is interpreted to be the result of a magnesium compound formation or to be the result of changes in flame temperature or more likely a combination of these two possibilities. The color convergence and wavelength relationship is interpreted to suggest that (a) the convergence line between the convergence point and the diagram intercept will define all colors for a particular metal system, (b) that the convergence point is influenced by a metal emitter and flame temperature and (c) that the point of intercept represents the dominant emitting specie for that system.

## 6. VALIDITY

It is emphasized that the interpretations and suggestions advanced herein are not conclusions. Additional exploration of these phenomena will be required to provide more substantial evidence to support the generalizations. However, the observations are reported in an effort to stimulate the expression and extension of ideas related to this subject.

## 7. ACKNOWLEDGMENTS

The work was sponsored by the Bureau of Naval Weapons (RMMO-3). The observations and suggestions concerning additive mixtures by D. M. Johnson are gratefully acknowledged.

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Bernard E. Douda  
25 September 1964 11p.

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  2. Flares, Colored
  3. Emitters, Flame
  4. Emission, Flame
  5. Temperature, Flame
1. B. L. Douda

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